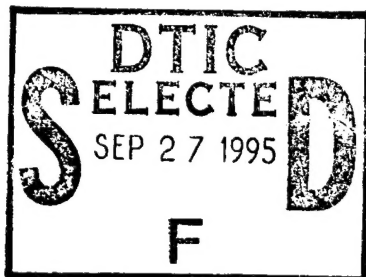Quarterly Status Report No. 1
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# CT-ASSISTED SOLID FREEFORM MANUFACTURING

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## 1.0  INTRODUCTION

Computed Tomography (CT) is a radiographic inspection method that uses a computer to reconstruct a cross-sectional image of an object from a set of in-line X-ray transmission measurements. CT was introduced in the early 1970's as a neurological examination technique and later extended to industrial applications by Advanced Research and Applications Corporation (ARACOR) and others. The original medical acronym, CAT, is still widely used and is likely to be familiar to the reader. The technology provides an ideal examination technique whenever the primary goal is to locate and size planar or volumetric detail in three dimensions. Because of the relatively good penetrability of X rays, as well as the sensitivity of absorption cross sections to the density and atomic number of matter, CT permits the nondestructive physical and, to a limited extent, chemical characterization of the internal nature of objects. And since the method is X-ray based, it applies equally well to metallic and non-metallic specimens, solid and fibrous materials, smooth and irregularly surfaced parts.

A key advantage of CT is that it can nondestructively obtain images of both exterior and interior surfaces and regions of an object. Because CT images are densitometrically accurate, complete morphological and part characterization information can be obtained without need for physical sectioning. With CT, complete 100% examinations can be obtained in a few hours, independent of part complexity. This data can be processed to create CAD representations of the part, to extract dimensional measurements, or to detect, size and locate defects. Current industrial CT systems have progressed to the point where they can provide dimensional measurements of a part with accuracies competitive with coordinate measuring machines (CMMs). However, unlike CMMs, CT systems can obtain thousands of measurements simultaneously, without special pre-programming, of internal as well as external surfaces, while also detecting flaws and defects. And because CT images are digital, they can be enhanced, analyzed, compressed, archived, retrieved, input to engineering calculations, and transmitted intramurally via local area network (LAN) or extramurally via the information super-highway.

As a result of these advantages, CT has emerged in the last few years as the leading modality for reverse engineering and part characterization applications. In 1988, the Air Force Wright Laboratory (WL) sponsored a Boeing-ARACOR team to investigate potential industrial applications of CT. Of the dozen or so generic application areas studied, the use of CT for reverse engineering and part characterization was ranked as the top commercially viable use. The WL technical report, "X-Ray Computed Tomography for Casting Development" (WL-TR-92-4032), concluded that "areas which would benefit [from the use of CT] include internal dimensional

1

measurements (eliminating destructive sectioning), specific region inspections, flaw characterization in critical regions (to allow passing or informed repair of castings), and geometric acquisition for CAD/CAM."

Like casting production, solid freeform manufacturing (SFM) is also a near-net-shape technology. Thus, the above conclusions are as applicable to SFM practices as to castings. A model of the relationship between CT and SFM is presented in the figure. As illustrated, CT can be used to create "virtual objects" from existing objects. The process of scanning a part, extracting part contours from a CT image, and converting the data to a CAD-compatible format is commonly referred to as CT-assisted reverse engineering. Conversely, when a part is fabricated from a CAD model, CT can be used to nondestructively examine (NDE) the end product. The process of CT scanning a part, extracting defect and dimensional data from an image, and generating a variance report is commonly referred to as CT-assisted part characterization. Together, CT-assisted reverse engineering and part characterization form a complementary pair. Both are essential elements of a powerful dynamic with the ability to drive and accelerate the development of SFM equipment, methods and processes.
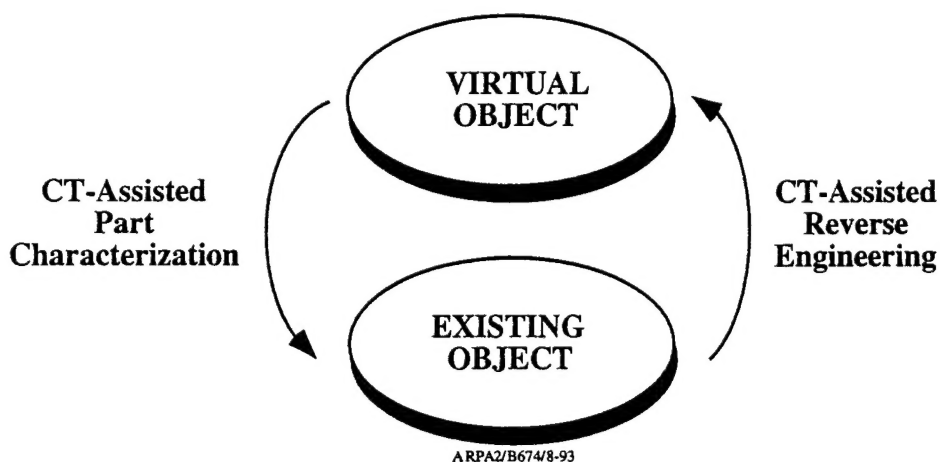


**CT-Assisted Solid Freeform Manufacturing.**

## 2.0   PROGRAM OBJECTIVES

In response to the Advanced Research Projects Agency (ARPA) Broad Area Announcement (BAA) 93-24, "Solid Freeform Manufacturing," ARACOR successfully proposed the development and demonstration of CT-assisted solid-freeform manufacturing practices. The project will provide critical reverse engineering and part characterization functions common to all ARPA-sponsored SFM activities. The goal is to facilitate the timely transition of CT-assisted

reverse-engineering, dimensional verification and defect detection practices to the SFM manufacturing community. To meet this goal, the following major technical objectives have been established:

• *Develop application software to make CT-assisted manufacturing practices available to the SFM community.* The application will run on a variety of common workstation platforms, accept data from different CT scanners, and output results in various formats to facilitate reverse engineering, dimensional verification and report generation. The SFM software tools will be derived from existing capabilities previously developed for the investment casting industry and from capabilities defined during interactions with other BAA participants.

• *Provide the SFM community access to CT-assisted reverse engineering, dimensional verification, and defect detection services.* Through ARPA, BAA participants will be able to request access to CT scan and analysis services. Access to high-resolution ($< 25\mu$) CT scans will be provided for structural ceramics and other composites needing high-definition nondestructive evaluation (NDE) imaging, and access to high-energy (~9 MV) CT scans will be provided for metallic and other components needing large-structure NDE imaging. CAD, dimensional and defect information will be extracted from image data by ARACOR and provided to other BAA participants.

• *Transfer CT-assisted manufacturing practices to the SFM industry by beta siting application software and training users in its operation.* The SFM application software will be installed at beta-site locations designated by ARPA and recipients instructed in its use. As directed by ARPA, ARACOR staff will travel to BAA participant sites to demonstrate the extraction and analysis of CT-derived data with the proposed SFM application software.

## 3.0  WORK PLAN

The Work Breakdown Structure (WBS) for the above activities comprises the following three technical and one management tasks:

Task 1. Develop CT-Assisted SFF Software Application. ARACOR shall develop a software package to make CT-assisted SFF manufacturing practices universally accessible to system-level designers. First, ARACOR shall integrate existing ARACOR reverse engineering and dimensional verification tools into a pre-commercial version of a software application that can run on a variety of common workstations (WBS 1.1). At a minimum, versions which run on Silicon Graphics, Sun and IBM workstations will be developed. Following that, ARACOR shall develop

and integrate advanced analysis tools specially tailored for SFM composites into the application (WBS 1.2). The application will allow users to input CT data from a variety of CT systems and output results in formats suitable for reverse engineering, dimensional verification and report generation purposes. The application will feature an intuitive graphical user interface and networking capabilities for transferring data between workstations. Task 1 will run through years 1 and 2 and will be complete when the beta-site version of the application is ready for release.

Task 2. Provide Access to CT-Assisted Manufacturing Services. ARACOR shall provide CT-assisted reverse engineering (WBS 2.1), dimensional verification (WBS 2.2) and defect detection (WBS 2.3) services to the SFM community. Access to high-resolution and high-energy CT scan services are included. The work plan proposes that all requests for services will be directed to and approved by ARPA. The work plan assumes that the demand for analysis services will concentrate in the first two years while the SFM application software is being developed and will decrease during the third year once other BAA participants are provided beta-site versions of the necessary CT software tools (see Task 3). The work plan also assumes that scan services will be provided throughout the three-year SFM program to support third-year technology insertion efforts. Task 2 will be complete when the level of effort budgeted for these services has been expended.

Task 3. Transition CT-Assisted Practices to Industry. ARACOR shall install the software application at beta sites specified by ARPA and train participants in the use of CT-assisted SFM manufacturing practices (WBS 3.0). Up to three beta-site locations for the application may be selected. The work plan proposes that CT scan data be provided as part of Task 2 and that ARACOR travel to participant sites to provide on-site training and assistance in the application of CT-assisted flaw detection, dimensional verification and reverse engineering practices. At ARPA's direction, ARACOR will provide up to twelve trips for staff specialists to BAA participant sites to assist with the analysis of the scan data and to train designers in the use of the software. This will have the added benefit of providing ARACOR direct pre-commercial-release feedback from the SFM industry about the performance of the product. Task 3 will run during the third year and will be complete when the level of effort budgeted for these activities has been expended.

Task 4. Manage Program and Prepare Reports. ARACOR shall provide program management (WBS 4.1) for the duration of the contract and shall satisfy the contract data requirements list (CDRL) associated with the program. In particular, ARACOR will submit Quarterly Progress reports (WBS 4.2) and a Final Report (WBS 4.3) in the company's standard format. The sole deliverables associated with this program are beta versions of the software application, the quarterly Progress Reports, and the Final Report.

## 4.0 EXECUTIVE SUMMARY FOR REPORT PERIOD

- A program kickoff meeting was attended (WBS 4.1).

- Program management apparatus was established (WBS 4.2).

- The design of the application software began (WBS 1.1).

## 5.0 TECHNICAL DISCUSSION

Program activity this quarter was minimal due to lack of available technical staff. The main technical effort was the top-level design of the software application. The software functional requirements were outlined and a hypercard prototype of the graphical user interface was developed to test-drive the application. Development of both continues. ARACOR staff also attended a kickoff meeting of the ARPA SFM team members held at the University of Texas at Austin on August 10, 1994. Representing ARACOR were Jim Stanley, Imaging Technologies Manager, and Rich Calliger, Software Manager.

Programs are tracked at ARACOR using Cost/Schedule Status Reports (C/SSR) based on earned value. The basic framework was established but the final allocation of resources remains incomplete pending the final top-level software design. Beginning the next time and continuing each report period thereafter, the progress report will include cumulative man-hours, funds, and outstanding commitments expenditure data by task. It will also include a Program Schedule showing planned and revised activities forecasts, a Funds Expenditure Graph showing the planned-versus-actual total-dollar expenditures, a Work Completed Graph showing planned-versus-actual earned-value milestones, and a Cost/Schedule Status Report showing program progress and Latest Revised Estimates (LREs) to complete by task. Along with the C/SSR will be a series of reports explaining variances greater than 10% of the cumulative work scheduled.

## 6.0 ANTICIPATED ACTIVITIES FOR NEXT REPORT PERIOD

- The top-level design will be completed and technical development will begin.

- The financial tracking apparatus will be finalized and implemented.

- The second quarterly report will be prepared.